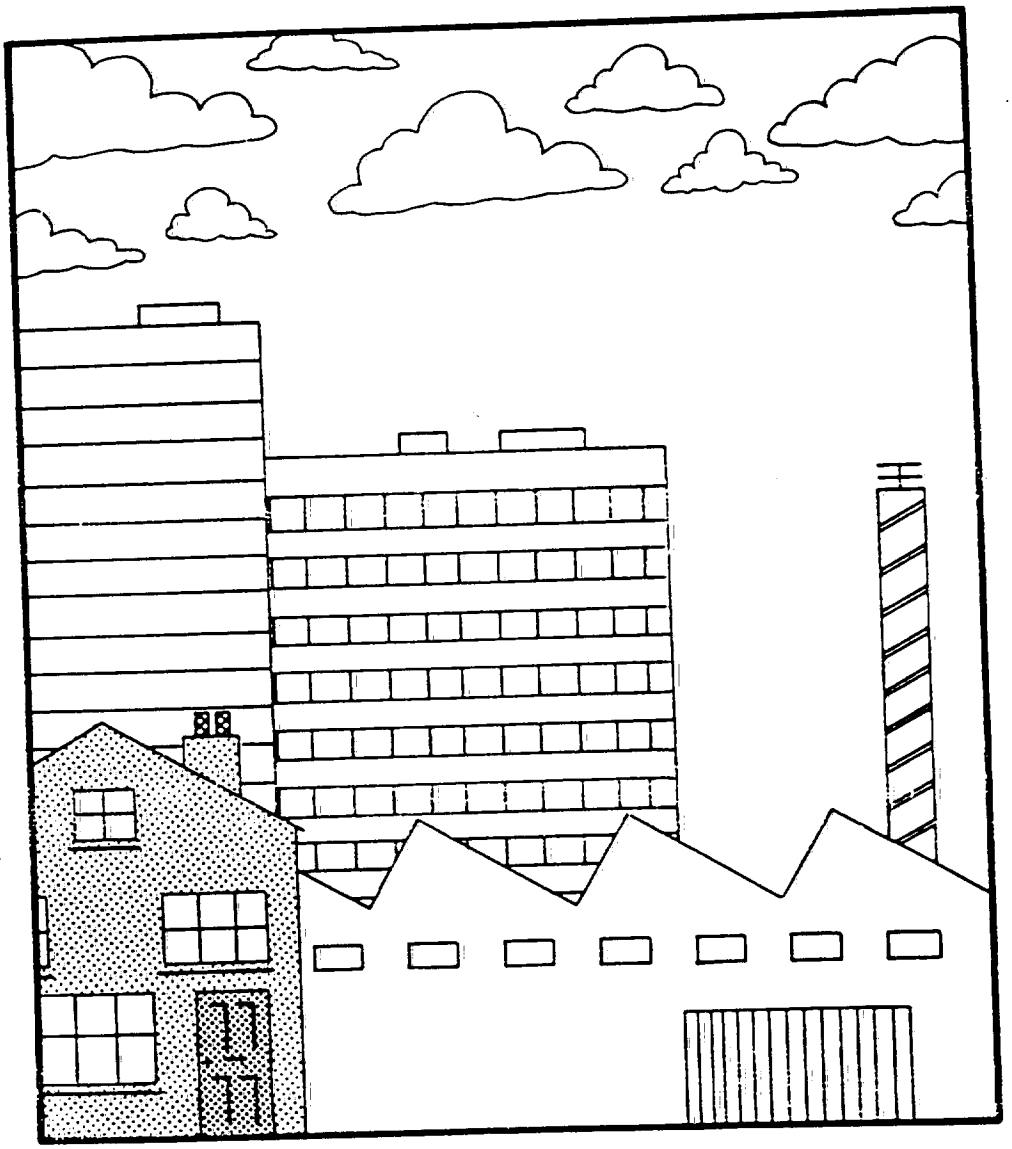
# INDOOR AND AMBIENT AIR QUALITY





Edited by R. Perry
and P.W. Kirk

SP

# INDOOR AND AMBIENT AIR QUALITY

Sold and distributed by Publications Division,
Selper Ltd., 79 Rusthall Avenue,
Chiswick, London W4 1BN

ISBN 0 948411 04 X



Published by
Publications Division, Selper Ltd., London
Printed by Printext Ltd., London

# ETS CONCENTRATIONS UNDER DIFFERENT CONDITIONS OF VENTILATION AND SMOKING REGULATION

T.Sterling

Faculty of Applied Sciences, Simon Fraser University, Burnaby, B.C. V5A 1S6, Canada

ABSTRACT

Concentrations of nicotine, respirable particulates (RSP), carbon monoxide (CO) and carbon dioxide ($CO_2$) were measured in offices under conditions of: smoking ad lib; smoking prohibited; smoking prohibited but receiving recirculated air from designated smoking areas that are not separately ventilated; smoking prohibited and smoking in designated areas that are separately ventilated.

## INTRODUCTION

Smoking is being rapidly regulated in public buildings especially in offices. The source of regulation usually is management, acting sometimes under pressure by non smoking employees. However, an increasing number of municipalities are passing bylaws setting the framework for smoking regulation in offices. Departments of the federal government, and units within these departments may develop their own smoking policies. The Canadian Federal Government is in the process of developing a general smoking policy for all its employees. Other areas than those serving as offices may also fall under smoking regulations. For instance, a number of Canadian provincial and federal courts have set aside non smoking jury rooms.

Smoking regulations may be of four basic types. Smoking may be prohibited entirely; or to the contrary, smoking may be permitted in the working area but under some local arrangements by which smokers and non smokers apportion the workspace among each other. In most instances, smoking may be restricted to a designated area, typically a cafeteria or a room usually serving as a coffee or lunch room.

Of these three options, the third will affect most office and public buildings.

In some buildings, the smoking designated area may be separately ventilated so that no component of Environmental Tobacco Smoke (ETS) may mix with the air circulating through the non smoking working areas. However, in many and possibly the majority of existing buildings, smoking will be designated to an area that is physically separate from the work area but is not separately ventilated. Components of ETS from such areas could mix with the recirculated air penetrate non smoking areas but in some diluted form.

Because of the different types of interaction between a building's ventilation and location of its smoking areas, a number of questions concerning air quality arise. Of these, two questions are of special interest. The first concerns the contribution of smoking to ambient levels of substances related to ETS, most importantly to nicotine, CO, $CO_2$, and respirable particulates (RSP) and the second asks just how does restricting smoking to specially designated but not separately ventilated areas affect the levels of ETS related substances in non smoking offices?

This report presents the results of two separate field studies of ETS levels in Canadian offices under conditions of normal occupancy, smoking and ventilation, and where in some cases designated smoking areas were, and in some cases were not, separately ventilated.

## METHODS

### FIELD STUDY I

In the first study, the number of office occupants and number of cigarettes smoked were observed while ambient levels of nicotine, CO and $CO_2$ were measured on the 7th and 11th floors of a government office building. Smoking was permitted *ad lib* on the 11th floor but was restricted on the 7th floor to a 22.5 $m^2$ (242 $ft^2$) coffee/smoking lounge where smoking was permitted at all times. The layout and design of the two floors were almost identical, with an open-area office of approximately 780 $m^2$ (8,400 $ft^2$) surrounding a 114 $m^2$ (1,230 $ft^2$) mechanical/service core.

Each floor had it's own independent ventilation system which recirculated between 80% to 85% of the air returned from each floor and provided at least 20 cfm (cubic feet per minute) of fresh air per person. Except for leakage through elevator shafts and stairwells, no mixing or recirculation of air between floors occurred. The coffee/smoking lounge on the 7th floor was on the same ventilation system as the rest of the 7th floor.

### FIELD STUDY II

In the second study, the number of office occupants and cigarettes smoked were observed while ambient levels of RSP, nicotine, CO and $CO_2$ were measured in two adjacent buildings (A and B) containing a mixture of open-area offices, private offices and public waiting/service areas.

Building A was a sealed, mechanically ventilated four storey office building with two levels of underground parking. Each of the four floors contained approximately 1,390 $m^2$ (15,000 $ft^2$) of office space. Smoking was prohibited in all areas of the building except for a smoking section, in the fourth floor cafeteria, which was not separately ventilated. The ventilation system mixed indoor air from all parts of the building before recirculation.

Building B was a 12-storey unsealed office building where most areas were passively ventilated by building leakage. Few areas had a separate ventilation system, and these systems were not connected to other ventilation systems. Consequently, there was no mechanical mixing of air from different floors or offices. Smoking was prohibited in all areas of the building

except in the smoking section of a basement cafeteria. Heated/cooled air was supplied separately to the cafeteria and exhausted through windows.

Sampling Methods

Nicotine:

In FIELD STUDY I, eight one-hour nicotine samples were collected in the designated smoking room, ten one-hour samples in the nonsmoking offices on the 7th floor, and ten one-hour samples in the smoking-permitted offices on the 11th floor. In FIELD STUDY II, six one-hour nicotine samples were collected in each of the smoking and nonsmoking sections of the cafeterias of Buildings A and B; two samples on each of the four floors in the nonsmoking offices of Building A and two samples in nonsmoking offices of Building B. Of the samples obtained in the nonsmoking offices of buildings A and B, six collected air for two hours, three collected air for four hours and one collected air for eight hours.

Ambient nicotine was sampled with a portable air sampling pump housed inside a briefcase. The sampling apparatus was designed to collect samples unobtrusively because of the previously noted effect of observation on occupant behavior (1). Nicotine samples were collected by pumping air at 1 litre per minute through sorbent tubes containing XAD-4 resin, a styrene divinylbenzene copolymer. The sorbent tubes contained 80 mg of resin in the front (primary) section and 40 mg in the rear (secondary) section. After sampling, the sorbent tubes were refrigerated until analysis.

The analytical procedure for nicotine was based on NIOSH (2). (Further detail of this procedure is given in Sterling (3)).

RSP:

RSP's were measured in FIELD STUDY II during the entire period of nicotine sampling and were averaged over each sampling period. RSP (particles less than 5 $\mu$m diameter) levels were measured with a Sibata Scientific Technology P-5H digital dust indicator which senses light side-scattered by suspended particles. The unit was calibrated at the factory to monodispersed stearic acid particles with a mean diameter of 0.3 $\mu$m. The digital counts of particles per sampling time were converted to RSP levels in $\mu g/m^3$.

CO and $CO_2$:

CO and $CO_2$ levels were measured over three to four minute periods approximately midway into the one- or two- hour nicotine sampling periods and at least twice during the four- and eight-hour nicotine sampling periods. CO was measured using a direct reading electrochemical analyzer (Nova 310L) housed in a flight-case. $CO_2$ was measured using extra low range $CO_2$ Gastec detector tubes and a manual sampling pump.

Other Observations:

During each sampling period, the number of occupants and the number of cigarettes smoked in each predefined observation area were recorded. The observation areas were defined by the ability to survey the area. For

purposes of comparison, the average number of persons per 10 $m^2$ and cigarettes smoked per hour per 10 $m^2$ were calculated.

## RESULTS

### FIELD STUDY I

Table 1 presents the average concentrations of nicotine, CO and $CO_2$, the average number of persons per 10 $m^2$, and the number of cigarettes smoked per hour per 10 $m^2$ (where applicable) for the smoking-permitted and nonsmoking floors and the designated smoking area.

TABLE 1

Comparison of ETS Related Air Quality Variables (Averages) in Smoking Prohibited and Permitted Work Areas and in Designated Smoking Areas
FIELD STUDY I

| | Nicotine ($\mu g/m^3$) | CO (ppm) | $CO_2$ (ppm) | Persons per 10$m^2$ | Cigarettes/ hour/10$m^2$ |
|---|---|---|---|---|---|
| Smoking Permitted | 4.8 | 2.5 | 720 | 0.79 | 0.36 |
| Smoking Prohibited | <1.6 | 2.1 | 680 | 0.61 | NA |
| Designated Smoking | 75 | 4.2 | 960 | 0.97 | 3.90 |

Although the three areas differed substantially in the number of cigarettes smoked per hour per 10 $m^2$, only ambient nicotine levels responded in a similar fashion. For example, the average smoking intensity (cigarettes per hour per 10 $m^2$) was 10.8 times greater in the smoking designated area than in the smoking-permitted floor. Similarly, the average ambient nicotine level was 15.6 times greater in the smoking designated than the smoking-permitted areas. Corresponding ratios for $CO_2$ and CO were only 1.3 and 1.7 respectively.

Smoking was not observed on the nonsmoking floor. The average ambient nicotine concentrations were below the limit of detection (i.e. less than 1.6 $\mu g/m^3$) for the one hour sampling periods used. CO and $CO_2$ levels were slightly lower on the nonsmoking floor than on the smoking-permitted floor.

Table 1 also lists the average person densities for each of the three sampling areas. The average person density was 30% higher on the smoking-permitted floor and 60% higher in designated smoking area than on the nonsmoking floor. Corresponding ratios calculated for CO and $CO_2$ show a similar pattern and range.

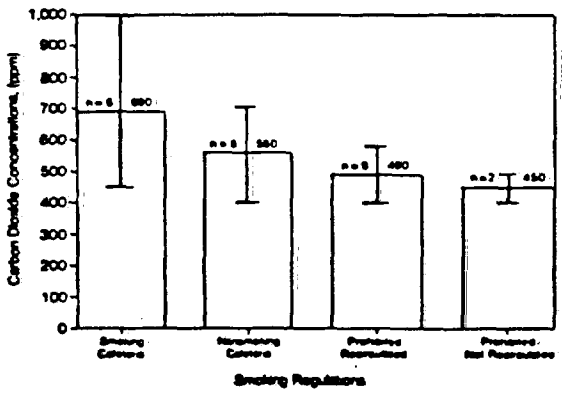
FIELD STUDY II

The data for the smoking and nonsmoking cafeteria sections of Buildings A and B were combined because there were only very small differences in the results for each building.

Figures 1 through 4 summarize the ambient $CO_2$, CO, RSP and nicotine concentrations, in four areas under different smoking and ventilation conditions: the smoking sections of the two cafeterias, the nonsmoking sections of the two cafeterias, the nonsmoking offices of Building A which received recirculated air from other areas of the building, and the separately ventilated nonsmoking offices of Building B which did not receive recirculated air from other areas of the building. In each figure, the height of the bars give the average concentration, n gives the total number of samples on which the average is based. The range of observed values is given by the vertical line.

Figure 1 shows that there was little difference between the $CO_2$ levels in the smoking prohibited offices of building A and building B, whether or not they received recirculated air. The smoking and nonsmoking sections of the cafeterias had slightly elevated, but not statistically significant, $CO_2$ concentrations when compared to the nonsmoking offices. These small increases in $CO_2$ levels could have been partly due to occupant density which was twice as high in the cafeteria sections than in the nonsmoking offices.

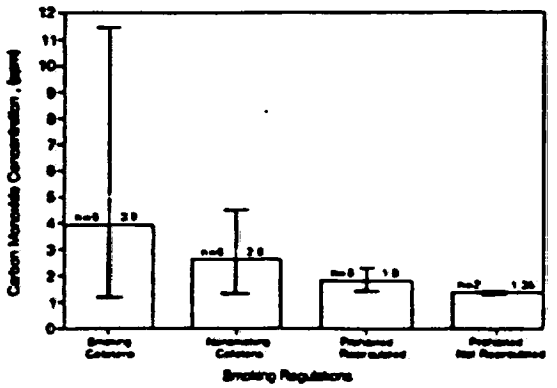
Figure 1
Comparison of Averages and Ranges of $CO_2$ Concentrations for Different Smoking Regulations




The distribution of mean ambient CO levels is similar to that for $CO_2$, as shown in Figure 2. Although mean CO levels were higher in both cafeteria sections than in the nonsmoking offices, none of the differences were statistically significant.

Figure 2

Comparison of Averages and Ranges of CO Concentrations for Different Smoking Regulations




There were no differences in RSP concentrations between the nonsmoking offices with and without recirculated air, as shown in Figure 3. However, the mean RSP level in the smoking section of the cafeterias was 2.6 times that in the nonsmoking offices while the mean level in the nonsmoking section of the cafeterias was about 1.7 times that found in nonsmoking offices.

Figure 3

Comparisons of Averages and Ranges of RSP Concentrations for Different Smoking Regulations

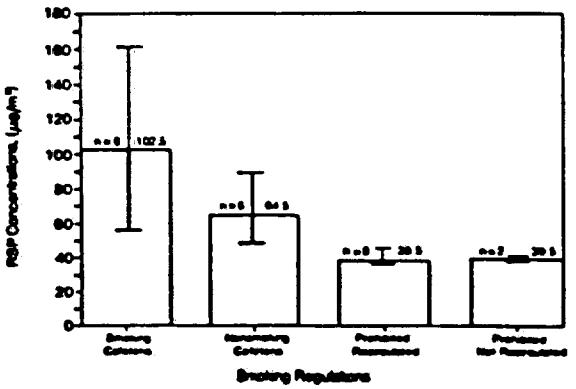
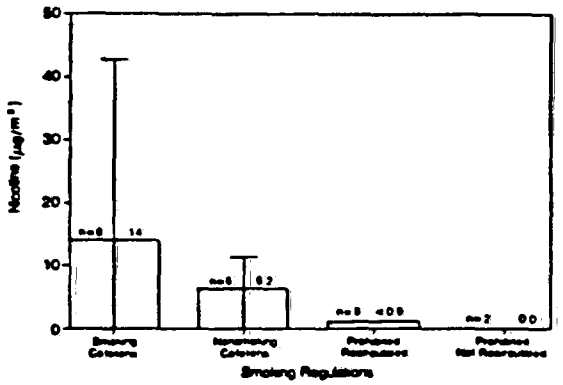



Figure 4 gives average ambient nicotine concentrations. In some instances the nicotine levels in the cafeteria sections were below the detection limit of 1.6 $\mu g/m^3$. The mean nicotine concentration measured in the smoking sections of the cafeterias was more than twice that in the nonsmoking sections of the cafeterias and at least 15 times that in the nonsmoking offices which received recirculated air.

Figure 4

Comparison of Averages and Ranges of Nicotine Concentrations for Different Smoking Regulations




The lower detection limit for nicotine is dependent upon the amount of air that is sampled. For the method used in this study, the lower detection limit was 0.8 $\mu g/m^3$ for a two-hour sample, 0.4 $\mu g/m^3$ for a four-hour sample, and 0.2 $\mu g/m^3$ for an eight-hour sample. Two-, four-, and eight-hour samples were taken in nonsmoking offices in Building A which received recirculated air. None of four two-hour samples were above the detection limit; one of three four-hour samples was above the detection limit and gave a determination of 1.0 $\mu g/m^3$; the single eight-hour sample was also above the detection limit and yielded a determination of 0.8 $\mu g/m^3$. These results indicate that the ambient nicotine concentration in these nonsmoking offices was not larger than the maximum positive result of 1.0 $\mu g/m^3$.

Two two-hour nicotine samples were taken in nonsmoking offices in building B which did not receive recirculated air. Nicotine was below the detection limit of 0.8 $\mu g/m^3$ in both samples.

## DISCUSSION

The FIELD STUDY I results suggest that ETS contributes little to ambient $CO_2$ levels. The differences in $CO_2$ concentrations between the smoking-permitted, prohibited and designated smoking areas were small compared with the observed differences in smoking intensity (cigarettes smoked per hour per 10 $m^2$) and ambient nicotine levels. However, the sample sites with higher $CO_2$ levels in FIELD STUDIES I and II also had higher person densities. This suggests that people were the primary source of $CO_2$.

Ambient CO concentrations increased with smoking (Table 1 and Figure 2) but did not closely follow smoking intensity or nicotine concentrations. Other indoor and outdoor sources of CO must also contribute to CO levels, as indicated by the background level of 1.35 ppm in the nonsmoking office

without air recirculation. Part of the higher CO level in the cafeteria could also be due to cooking activities.

RSP are produced both by smoking and by many other processes. The background RSP level, as indicated by the results for the nonsmoking office without recirculated air, are about 39 $\mu g/m^3$.

Not surprisingly, of the four substances measured, nicotine shows the strongest association with smoking. There are few if any significant sources of nicotine in the non-industrial indoor environment other than smoking and it follows that nicotine is an accurate marker of ETS exposure. Improvements in nicotine measurement technology could result in the widespread use of nicotine as an indicator of ETS exposure (4).

Restricting smoking to specially designated areas which are not separately ventilated appears to effectively prevent high ETS levels in adjacent nonsmoking areas. Both RSP and nicotine concentrations declined sharply from the smoking to the nonsmoking sections of the cafeterias in Buildings A and B (Figures 3 and 4). The recirculation of air from the smoking and nonsmoking sections of the Building A cafeteria further diluted ETS to the extent that the levels of CO, $CO_2$, and RSP in the nonsmoking offices of Building A were approximately the same as those levels in the nonsmoking office in building B, which did not receive recirculated air.

Nicotine levels were at or below 1 $\mu g/m^3$ in nonsmoking offices which receive recirculated air from smoking designated areas. This level of exposure is very low. For example, breathing air which contains 1.0 $\mu g/m^3$ of nicotine for one hour at an average respiration rate for office activity of 0.48 $m^3/hr$ (5) is approximately equal to 1/1,900th of the 900 $\mu g$ of nicotine inhaled by a smoker from the mainstream smoke of one cigarette (6).

There are few published studies of nicotine levels in nonsmoking offices. The nicotine levels observed by Bayer and Black (7) are, unfortunately, not comparable with the results given here because their results are given in $\mu g/m^3/min$. Nevertheless, they did not detect nicotine in two of three nonsmoking offices.

Other office studies have also found low RSP levels in nonsmoking areas close to smoking designated areas that are not separately ventilated (8). These findings are reinforced by Health and Welfare Canada (1) who measured RSP, CO and $CO_2$ concentrations before and after the implementation of a no smoking policy in offices that received recirculated air from a designated smoking area. After the no smoking policy was implemented, mean RSP levels decreased by 8 $\mu g/m^3$, from 26 $\mu g/m^3$ to 18 $\mu g/m^3$ (HWC, 1985a).

Another Health and Welfare Canada study (9) measured RSP and $CO_2$ on three floors of an office building before and after the implementation of a no smoking policy. This study differed from the previous HWC study in that smoking was restricted to a separately ventilated area. Table 2 gives mean RSP concentrations for the three floors before and after the implementation of the no smoking policy. The average RSP concentration on the three floors decreased from 28.1 $\mu g/m^3$ to 21.1 $\mu g/m^3$, for a net reduction of 7 $\mu g/m^3$.

2023383943

TABLE 2

Comparison of RSP Mean Concentrations on Office Floors Before and After a No Smoking Policy was Implemented (Extracted from Health and Welfare Canada (9))

| | RSP ($\mu g/m^3$) | $CO_2$ (ppm) |
|---|---|---|
| Before No Smoking Policy | | |
| Floor A | 29.3 | 663 |
| Floor B | 30.0 | 614 |
| Floor C | 25.0 | 606 |
| Overall Average | 28.1 | 627 |
| After No Smoking Policy | | |
| Floor A | 22.7 | 591 |
| Floor B | 19.8 | 551 |
| Floor C | 20.8 | 503 |
| Overall Average | 21.2 | 551 |

The results of the FIELD STUDY II and the Health and Welfare Canada study (1) indicate that recirculated air from designated smoking areas contributes less than 8 $\mu g/m^3$ of RSP to nonsmoking offices which receive such air. Another Health and Welfare Canada study (9) further suggests that ad lib smoking in offices under normal ventilation and occupancy conditions contributes about 7 $\mu g/m^3$ of RSP. These findings are substantially different from the widely quoted estimate by Repace and Lowrey (10) that smoking increases RSP levels in offices by 170 to 200 $\mu g/m^3$. This estimate, also accepted by Health and Welfare Canada, is based on modelling exposures. However, Repace and Lowrey's estimate is up to 21 to 29 times greater than the observed effect of smoking on RSP levels in the two HWC studies and, in fact, is 5.3 to 6.3 times larger than the average RSP concentration of 31.8 $\mu g/m^3$ from all sources found in smoking designated areas in the Health and Welfare Canada study (9). These results further verify the results of a comparison of air pollutant measurements in a large number of buildings with and without smoking regulations (11). The study found only small differences in airborne particles (combined total and respirable particles).

While smoking regulations are here to stay and will affect most offices under federal, provincial or municipal control in Canada, the haste to regulate smoking may have been based on the unrealistic modelled estimates of Repace and Lowrey or on "worst case" measurements in poorly ventilated workplaces, instead of on actual measurements of RSP levels in typical offices.

The provision of a designated smoking area appears to effectively reduce ETS constituent levels in nonsmoking offices, even if the designated smoking area is not separately ventilated. However, we should caution that an exclusive reliance on regulating smoking while ignoring other sources of indoor pollution in the non-industrial work environment may accomplish little in meeting indoor air quality problems, especially in so-called "Sick Buildings" (11).

ACKNOWLEDGEMENTS

We thank Dr. J. Blatherwick and Mr. G. Rowlands from the City of Vancouver Health Department and Mr. R. Sue from the British Columbia Buildings Corporation for their help in making buildings and sampling sites available, and to Dr. C. Nystrom for help with some of the equipment used for SERIES 1. Part of the costs of this project came from a special grant from the Council for Tobacco Research Inc.

REFERENCES

1. Health and Welfare Canada, Investigation on the Impact of a New Smoking Policy on Office Air Quality National Library of Canada Hull, Quebec. Occupational Health Unit Medical Services Branch (1985).

2. NIOSH, Manual of Analytical Methods, 2nd ed. US National Institute of Occupational Safety and Health, Cincinnati, Ohio (1977).

3. T.D. Sterling and B. Mueller, Concentrations of nicotine, RSP, CO, $CO_2$ in nonsmoking offices ventilated by air recirculated from smoking designated areas. Am Ind Hyg Assoc J (in press).

4. Health and Welfare Canada, Involuntary Exposure to Tobacco Smoke, Report of the Advisory Committee, Environmental Health Directorate, Ottawa (1987).

5. ASHRAE, ASHRAE Standard 62-1981R, Ventilation for acceptable indoor air quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia (1986).

6. M. Muramatsu, S. Umemura, T. Okada and H. Tomita, Environ Res. 35, 218-227 (1984)

7. C.W. Bayer and M.S. Black, Passive smoking: Survey analysis of office smoking areas vs. environmental chamber studies. Atlanta, Georgia (Proceedings, ASHRAE IAQ'86, pp. 281-291) (1986).

8. H.K. Lee, Investigation of the impact of a new smoking policy on office air quality in the National Library of Canada in Hull, Quebec. Ottawa, Proceedings of the 78th Annual Meeting of the Air Pollution Control Association (1985).

9. Health and Welfare Canada, Investigation on the Impact of a New Smoking Policy on Office Air Quality Office of the Auditor General Ottawa, Ontario. Occupational Health Unit Medical Services Branch (1985).

10. J.L. Repace and A.H. Lowrey, Science 208, 464-472 (1980)

11. T.D. Sterling, C.W. Collett and E.M. Sterling, J Occup Med 29, 57-62 (1987)